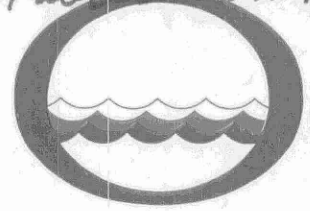


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Water Management in Ontario

Res. Publication # 32



RESEARCH
PUBLICATION
NO. 32



NUTRIENT - PHYTOPLANKTON

RELATIONSHIPS

IN EIGHT

SOUTHERN ONTARIO LAKES

THE ONTARIO WATER RESOURCES COMMISSION

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NUTRIENT - PHYTOPLANKTON RELATIONSHIPS
IN
EIGHT SOUTHERN ONTARIO LAKES

By:

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October, 1968

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SUMMARY

In situ relationships between nutrient availability and algal production were investigated simultaneously in eight lakes of the Trent River drainage basin. Three lakes were found to be oligotrophic, one-mesotrophic and four-eutrophic. No differences between lakes were evident with respect to levels of total phosphorus, inorganic nitrogen, sulfate or iron. Distinctions between lakes with respect to phytoplankton production were found to be directly related to alkalinity levels. Additions of oxidized inorganic or biodegradable carbonaceous material to a low alkalinity lake water were found to stimulate algal production when sufficient nitrogen and phosphorus were present.

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INTRODUCTION

The enrichment of surface waters due to the entry of nutritive materials via municipal wastewaters, agricultural runoff, etc., which often results in the formation of excessive quantities of algae, has received considerable attention in recent years (Mackenthun and Ingram, 1967) with particular emphasis being focused on the roles of the two chemicals, nitrogen and phosphorus (Mackenthun, 1965).

The nutritional aspects of algal growth have been investigated extensively by in vitro techniques utilizing axenic cultures (Chu, 1942; Fogg, 1965; Lewin, 1964). Estimation of the potential productivity of surface waters using laboratory bioassays has also been attempted (Skulberg, 1964). Extrapolation of responses obtained under these conditions to natural situations is quite limited, however, due to the indeterminate influences of such factors as vessel wall effects, lack of predation, antibiosis, to name only a few (Lund, 1965).

As the prevention of excessive algal growths with its associated problems of filter clogging, taste and odours and recreational impairment, is fundamental to proper water management, an understanding of the relationships between in situ nutrient availability and phytoplankton responses is a necessary prerequisite for the development of satisfactory methods of control.

The following report presents the results of a study carried out simultaneously in several lakes during 1967 to investigate the in situ relationships between phytoplankton development and the nutrient environment.

METHOD

Sampling of the lakes, which began in late April and continued at two week intervals when possible until late September, was accomplished by passing an open 40 oz bottle through a column of water which was twice the depth of the water transparency as determined by a 10 inch secchi disc. The reliability of this method of sampling to evaluate trophic relationships in surface waters has already been presented in a preliminary form and will be subsequently included in a report on algal studies carried out in the Bay of Quinte (Christie, 1967). Temperature readings were taken each time at three meter intervals to a depth of 15 meters.

Chemical determinations were carried out according to the procedures of Standard Methods, 12th Edition (APHA, 1965). Analyses obtained on a regular basis included:

suspended solids	mg/l
dissolved solids	mg/l
total alkalinity	mg/l CaCO_3
pH	mg/l
N. NO_3	mg/l
N. NH_3	mg/l
N. Organic	mg/l
PO_4 •total P	mg/l
PO_4 •soluble reactive P	mg/l
algae	ASU/ml
Chlorophyll <u>a</u>	ug/l

and on an intermittent basis:

calcium	mg/l
magnesium	mg/l
iron	mg/l
sodium	mg/l
potassium	mg/l
sulphate	mg/l
chloride	mg/l

Algal samples were immediately preserved with mercuric chloride and subsequently concentrated using the Sedgwick-Rafter sand filtration technique in conjunction with two layers of silk bolting cloth, having apertures of 25 u. Data, based on the enumeration of between 150-200 organisms, are expressed as ASU/ml (APHA, 1965).

Laboratory nutrient studies were carried out by placing 150 ml aliquots of raw lake water, obtained from a depth of one meter in Lake Kushog in early September, into 250 ml acid-washed, sterile cotton plugged flasks. The cultures, mounted on a slowly oscillating shaker, were illuminated with September daylight entering via northern exposed windows. Algal responses to the additions of the nutrients were determined by enumerating unconcentrated aliquots at regular intervals. The results are based on the average of two replications.

DESCRIPTION OF LAKES

The eight lakes examined in this study, which included Kushog, Twelve Mile, Gull, Balsam, Sturgeon, Buckhorn, Clear and Rice, form a part of a single major drainage basin, the Trent River System, with each lying adjacent to at least one of four major physiographic regions which influence the watershed (Figure 1) (Chapman and Putnam, 1962).

Kushog Lake

Kushog Lake, located on the precambrian shield in the upper northwest sector of the watershed, is approximately 12 miles in length with a maximum width of about one mile and a surface area of 2,316 acres. The lake consists of three major regions, an upper basin, north of Highway 35, approximately 2 miles by 1 mile, a middle zone $7\frac{1}{2}$ miles long with an average width of $\frac{1}{4}$ mile, and a lower complex of several bays. The depth in the upper and lower regions is about 5 meters and descends to almost 18 meters in the middle portion.

No communities of any size lie within the drainage basin of the lake nor are there any agricultural practices adjacent to the lake.

In April samples were obtained from the bridge at Ox Narrows. Sampling otherwise was about $1\frac{1}{2}$ miles to the south.

Twelve Mile Lake

Twelve Mile Lake, which also lies within the precambrian shield, is approximately 2.5 miles by 1 mile, with an area of 2,987 acres and an observed depth at the sampling location of 17 meters.

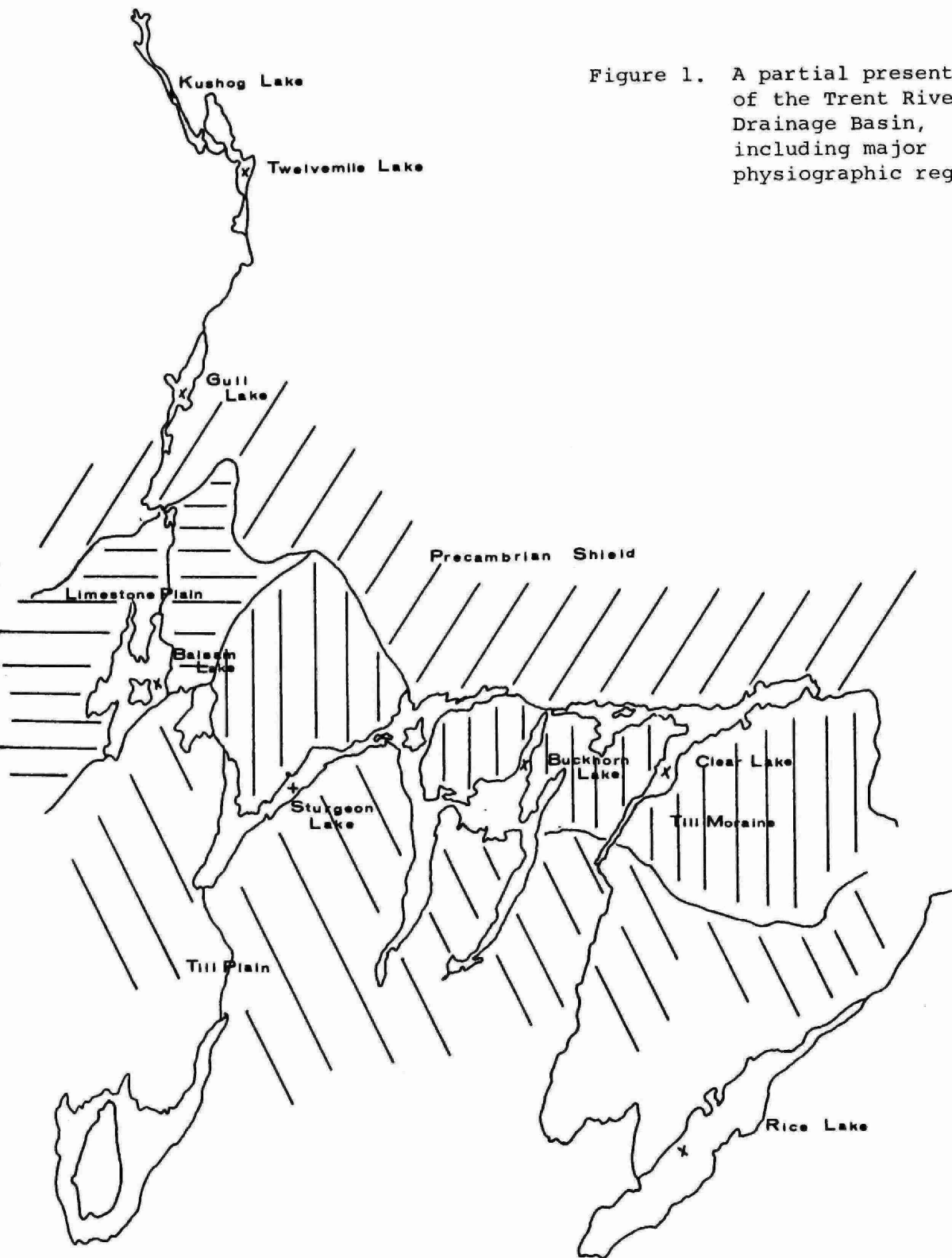


Figure 1. A partial presentation of the Trent River Drainage Basin, including major physiographic regions.

The lake receives effluent from Kushog and Boshkung Lakes. Several hamlets, such as West Guilford, Maple Lake and Hall's Lake, influence the discharge into Boshkung.

In April, samples were obtained from the outfall at Elsie, all other samples being collected at the middle of the lake.

Gull Lake

Gull Lake, as with the two lakes described above, also lies within the precambrian shield. The lake has an area of 2,641 acres and is approximately $6\frac{1}{4}$ miles long, about 1 mile wide and has an observed depth of 16 meters.

Principal discharge into the lake is via the Gull River which passes through the Town of Minden. A limited amount of agricultural practice in the surrounding terrain is also evident.

Samples in April were obtained at the outfall - Moore Falls, on May 12, Aug. 2 and Sept. 29 from Miner's Bay, otherwise out in the main body of the lake approximately $\frac{1}{2}$ mile east of Deep Bay.

Balsam Lake

Balsam Lake lies principally within the limestone plain (Figure 1) although the southeastern shore is composed of till plain material. The lake, which consists of four large bays, is about 9 miles long, $4\frac{1}{2}$ miles wide, with a maximum depth of 12 meters and covers an area of 11,000 acres.

The Gull River, which connects Gull and Balsam Lakes, passes through the communities of Norland and Coboconk. Waters into Balsam from the south and west originate in an extensive agricultural area.

Samples in April were obtained from the river at Rosedale, other sampling being carried out approximately halfway between Rosedale and Grand Island.

Sturgeon Lake

Sturgeon Lake, which is bordered on the north by the till moraine and on the south by the till plain physiographic regions (Figure 1), consists of two arms approximately $8\frac{1}{2}$ miles long and about $1\frac{1}{4}$ miles wide, has a surface area of 9,200 acres and a maximum depth approaching 13 mètres.

Principle sources of influent enter at each end of the westerly arm, the Fenelon River passing through the community of Fenelon Falls, and the Scugog River flowing through the City of Lindsay from Lake Scugog.

Sampling in April was from the dam at Bobcaygeon, all remaining samples being obtained in the middle of the lake off shore from the government wharf at Ancona.

Buckhorn Lake

Buckhorn Lake, which lies downstream from Sturgeon, is located to the northeast of Pigeon Lake and to the west of the Village of Buckhorn, and receives water from the above lake as well as Chemung Lake. The lake lies within the till moraine and is approximately 8 miles long and slightly less than $\frac{3}{4}$ miles wide, with an approximate area of 4,200 acres and a depth not exceeding 7 meters and more typically of about 3-4 meters.

Samples on April 29 and May 12, were taken at the dam in the Village of Buckhorn. Other samples were obtained in mid-channel approximately $\frac{1}{2}$ mile southwest of Buckhorn Narrows.

Clear Lake

Clear Lake lies to the south of Stony Lake and to the east of the Community of Burleigh Falls within the till moraine (Figure 1). The lake is approximately 4 miles long, 3/4 miles wide, with an area of about 3,700 acres and a depth approaching 14 meters.

Samples on April 29 and June 22, were obtained at the outfall at Young's Point, otherwise at approximately mid-lake.

Rice Lake

Rice Lake, located within a highly productive agricultural till moraine region, is approximately 22 miles in length, 2½ miles in width, with an area of 24,000 acres and a maximum depth of about 8 meters. The lake receives discharge principally from Clear Lake via the Otonabee River, which passes through the City of Peterborough, the largest community in the Trent Watershed.

Samples in April, were taken at the dam located at Hastings. All other samples were obtained approximately ½ mile northwest of a submerged causeway, about 1 mile from the northern shoreline.

RESULTS

Phytoplankton

Estimates of the standing crops of phytoplankton associated with each lake and their respective composition are depicted in Figure 2. These data have been further summarized in Table I to show the average composition of the standing crop for each lake.

Phytoplankton quantities (ASU/ml) in the eight lakes were compared taking into consideration influences due to time of sampling and taxonomic division (Figure 3). With respect to total ASU/ml, the lakes fall into two categories of four lakes, for example, Kushog was not significantly different from Twelve Mile, Gull and Balsam, but was dissimilar from Sturgeon, Buckhorn, Clear and Rice. Distinctions between lakes on the basis of the Bacillariophyta (diatoms) and the Cyanophyta (blue-greens) are apparent but did not occur with respect to the Chlorophyta (greens), Chrysophyta (yellow-greens) or Pyrrophyta (armoured flagellates).

Statistical analysis of algal levels between lakes based on chlorophyll determinations was also carried out using either concentrations per unit volume or per unit surface area (Figure 4). From the former, the lakes fall into three groups, while with the latter, no differentiation occurred.

A further insight into phytoplankton - lake relationships is provided in Table II, where the algal genera associated with each lake in the spring, summer and autumn have been listed. Genera containing members capable of being taste and odour producers or filter cloggers are also shown (16).

Figure 2. Estimated standing crops of algae (ASU/ml) and their percent composition in Kushog (K), Twelve Mile (T), Gull (G), Balsam (B), Sturgeon (S), Buckhorn (B'), Clear (C) and Rice (R) lakes.

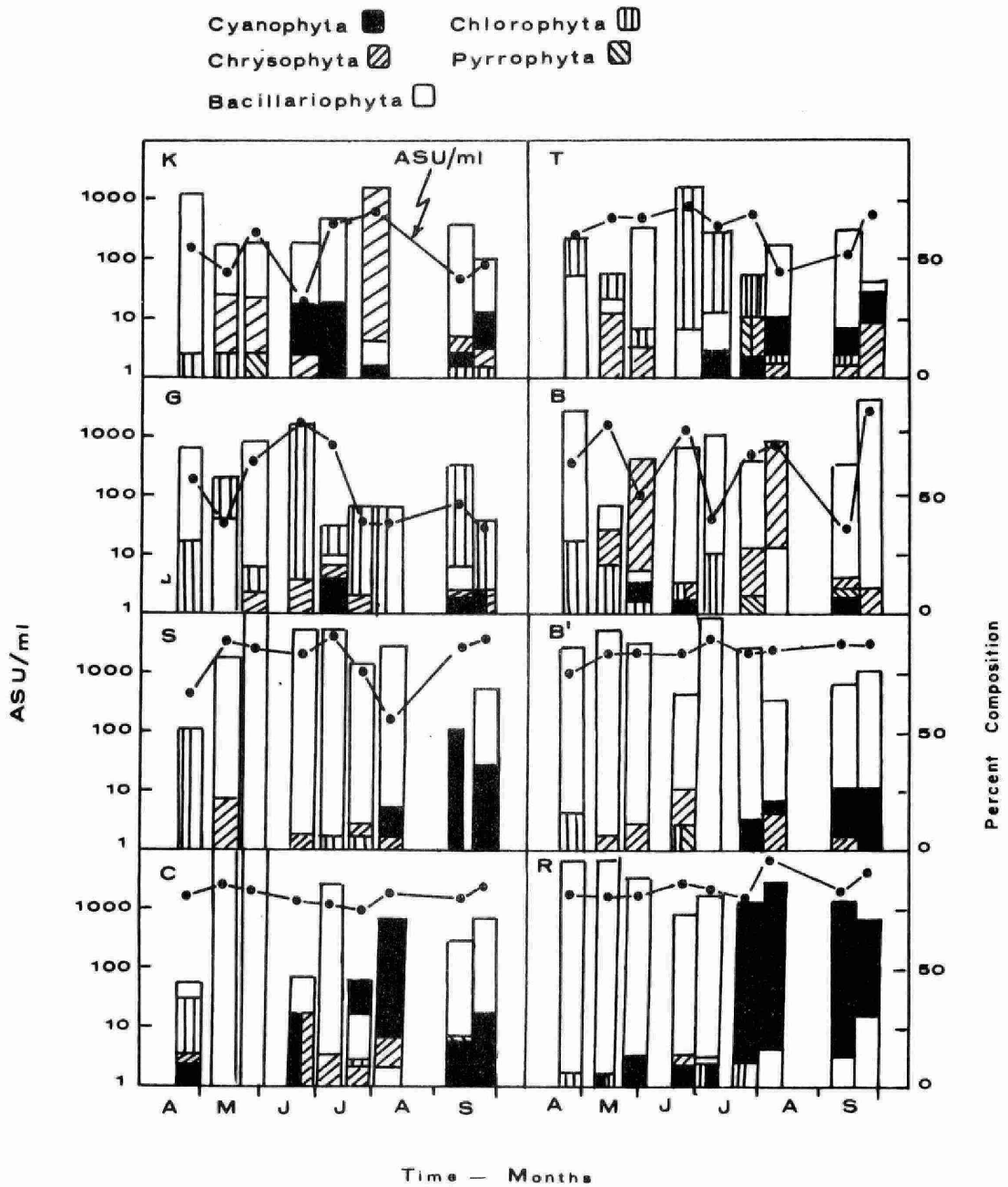


TABLE I

Average Percent Composition of the
Phytoplankton of Each Lake
Based on ASU/ml

Lake	Cyanophyta	Chlorophyta	Pyrrophyta	Chrysophyta	Bacil- lariophyta
Kushog	10.4	1.3	1.6	42.4	44.4
Twelve Mile	9.8	41.2	0.2	13.0	35.8
Gull	4.9	58.6	0.4	12.8	23.2
Balsam	1.5	7.9	0.8	23.1	66.5
Sturgeon	14.4	2.7	0.5	3.3	79.1
Buckhorn	10.4	2.6	0.7	6.4	79.8
Clear	21.6	5.6	3.1	8.4	61.3
Rice	48.1	3.3	0.9	2.2	45.4

Figure 3. Comparison of lakes on the basis of phytoplankton quantities (ASU/ml).

	K	T	G	B	S	B'	C	R	Ave
Kuehog	K	/	/	/					219
Twelvemile	T	/	/	/	/				459
Gull	G	/	/	/	/				387
Balsam	B	/	/	/	/				829
Sturgeon	S				/	/	/	/	2282
Buckhorn	B'				/	/	/	/	2445
Clear	C				/	/	/	/	1909
Rice	R				/	/	/	/	2504

Total ASU/ml

	K	T	G	B	S	B'	C	R	
K	/	/	/	/	/	/	/	/	22
T	/	/	/	/	/	/	/	/	45
G	/	/	/	/	/	/	/	/	20
B	/	/	/	/	/	/	/	/	13
S	/	/	/	/	/	/	/	/	330
B'	/	/	/	/	/	/	/	/	256
C					/	/	/	/	412
R							/	/	1258

Cyanophyta

	K	T	G	B	S	B'	C	R	
K	/	/	/	/	/	/	/	/	3
T	/	/	/	/	/	/	/	/	189
G	/	/	/	/	/	/	/	/	233
B	/	/	/	/	/	/	/	/	66
S	/	/	/	/	/	/	/	/	61
B'	/	/	/	/	/	/	/	/	64
C	/	/	/	/	/	/	/	/	107
R	/	/	/	/	/	/	/	/	87

Chlorophyta

	K	T	G	B	S	B'	C	R	
K	/	/	/	/	/	/	/	/	4
T	/	/	/	/	/	/	/	/	1
G	/	/	/	/	/	/	/	/	1
B	/	/	/	/	/	/	/	/	7
S	/	/	/	/	/	/	/	/	11
B'	/	/	/	/	/	/	/	/	18
C	/	/	/	/	/	/	/	/	60
R	/	/	/	/	/	/	/	/	24

Pyrrophyta

	K	T	G	B	S	B'	C	R	
K	/	/	/	/	/	/	/	/	9
T	/	/	/	/	/	/	/	/	60
G	/	/	/	/	/	/	/	/	51
B	/	/	/	/	/	/	/	/	192
S	/	/	/	/	/	/	/	/	75
B'	/	/	/	/	/	/	/	/	158
C	/	/	/	/	/	/	/	/	160
R	/	/	/	/	/	/	/	/	59

Chrysophyta

	K	T	G	B	S	B'	C	R	
K	/	/	/	/	/	/	/	/	98
T	/	/	/	/	/	/	/	/	164
G	/	/	/	/	/	/	/	/	93
B	/	/	/	/	/	/	/	/	551
S					/	/	/	/	1805
B'					/	/	/	/	1950
C						/	/	/	1170
R							/	/	1413

Bacillariophyta

Figure 4. Comparison of lakes on the basis of chlorophyll a - ug/l or mg/meter².

	K	T	G	B	S	B'	C	R	Avg
K		✓	✓	✓					1.4
T	✓		✓	✓					1.4
G	✓	✓		✓					1.5
B	✓	✓	✓						1.6
S						✓	✓		5.2
B'					✓		✓		7.1
C					✓	✓			4.8
R									9.7

Chlorophyll a (ug/litre)

	K	T	G	B	S	B'	C	R	Avg
K		✓	✓	✓	✓	✓	✓	✓	7.8
T	✓		✓	✓	✓	✓	✓	✓	7.7
G	✓	✓		✓	✓	✓	✓	✓	5.9
B	✓	✓	✓		✓	✓	✓	✓	5.2
S	✓	✓	✓	✓		✓	✓	✓	13.5
B'	✓	✓	✓	✓	✓		✓	✓	19.1
C	✓	✓	✓	✓	✓	✓		✓	14.6
R	✓	✓	✓	✓	✓	✓	✓		17.5

Chlorophyll a (mg/m²)

TABLE II

Algal Genera Associated with Each Lake

	<u>Spring</u>	<u>Summer</u>	<u>Autumn</u>	<u>Potential</u>	
	<u>KTGBSBCR</u>	<u>KTGBSBCR</u>	<u>KTGBSBCR</u>	<u>Taste</u>	<u>Filter</u>
<u>Chlorophyta</u>				<u>Prod.</u>	<u>Clog</u>
<u>Ankistrodesmus</u>	xxxxxxxx	xxx xxx			
<u>Arthrodesmus</u>		x			
<u>Chlorella</u>	xxxxxxxx				
<u>Chlorococcum</u>			x		
<u>Closterium</u>	x			x	x
<u>Coelastrum</u>		x			
<u>Dactylococcus</u>		x x			
<u>Dictyosphaerium</u>		xx xx	xx	x	x
<u>Euastrum</u>		x x	x		
<u>Gleocystis</u>		x x		x	
<u>Pediastrum</u>	xx x	xxxxx		x	
<u>Scenedesmus</u>	xx x	x x			
<u>Schroderia</u>		x			
<u>Staurostrum</u>	x	xxxx xx	x	x	
<u>Volvox</u>	x			x	
<u>Pyrrophyta</u>					
<u>Ceratium</u>		xxxxxxx	x x	x	
<u>Peridinium</u>	x x	x x xx	x	x	x
<u>Chrysophyta</u>					
<u>Chrysosphaerella</u>		xx xx x	xx	x	
<u>Dinobryon</u>	xxxxxxx	xxxxxxx	xxxx x	x	x
<u>Cyanophyta</u>					
<u>Anabaena</u>	x	xxxxxxxx	xxxxxx	x	x
<u>Anacystis</u>	x			x	x
<u>Aphanizomenon</u>	x	xxxx	xxxx	x	
<u>Aphanocapsa</u>		xxxx	x		
<u>Chroococcus</u>	x	xxxx x x	xxxx x x		
<u>Coelosphaerium</u>		x x			
<u>Gleocapsa</u>		xxx			
<u>Gomphosphaeria</u>		x	xx		

	<u>Spring</u>		<u>Summer</u>	<u>Autumn</u>	<u>Potential</u>	
	<u>KTGBSBCR</u>		<u>KTGBSBCR</u>	<u>KTGBSBCR</u>	<u>Taste</u>	<u>Filter</u>
					<u>Prod.</u>	<u>Clog</u>
<u>Lyngbya</u>	x	x	xx			
<u>Merismopedia</u>			x			
<u>Microcystis</u>		x	xxxx			
<u>Oscillatoria</u>	x		xx		x	x
<u>Bacilliarophyta</u>						
<u>Asterionella</u>	xxxxxxxx		xxxxxxxx	xxxxxxxx	x	x
<u>Cyclotella</u>	x x				x	x
<u>Fragillaria</u>	xx xxxxx		xxxxxxxx	xxxxxxxx	x	x
<u>Navicula</u>	x		x			
<u>Melosira</u>	xxxxxx		xxxxxx	xxxxxx	x	x
<u>Stephanodiscus</u>	x xx		x xxxxx	x xx	x	x
<u>Synedra</u>	xx x				x	x
<u>Tabellaria</u>	xxxxxxxx		xxxxxxxx	xxxxx x	x	x

Chemistry and Physics

The average concentrations of the various chemical parameters determined for each lake are summarized in Table III. Isothermal patterns ($^{\circ}\text{C}$) and transparency are illustrated in Figure 5.

Statistical analyses of certain parameters were carried out to determine which factors may have been most contributory in creating the differences between lakes obtained with standing crops (Figure 3). Data examined in this manner included total phosphorus as phosphate, inorganic nitrogen, sulfate, iron (Figure 6), pH, alkalinity, calcium, total dissolved solids (Figure 7), transparency and the average temperatures of the sampled water columns (Figure 8).

Significant differences between lakes which could range from zero to eight occurred in the following ascending order:

- zero - total phosphate, inorganic nitrogen, iron, sulphate
- three - pH, hardness, total dissolved solids
- four - temperature
- six - alkalinity

Possible correlations between phytoplankton quantities as ASU/ml or chlorophyll a ug/l and total phosphate, inorganic nitrogen and/or alkalinity, were tested by carrying out polynomial regression analysis to the third degree (Table IV). No correlation was found between the parameters of production and total phosphate or inorganic nitrogen.

TABLE III

Average Concentration of Various
Chemicals (mg/l) Associated with Each Lake

	Kushog	Twelve Mile	Gull	Balsam	Sturgeon	Buckhorn	Clear	Rice
Ca ⁺⁺	5.0	6.3	8.1	17.5	31.7	31.5	27.5	31.7
Mg ⁺⁺	1.5	2.0	2.0	2.7	3.2	3.0	3.2	3.7
Na ⁺	1.0	1.2	1.1	1.2	2.1	2.1	2.0	2.1
K ⁺	0.5	0.7	0.7	0.7	0.9	0.8	0.8	0.9
Fe ⁺⁺⁺	0.10	0.05	0.18	0.07	0.09	0.04	0.08	0.14
HCO ₃ ⁻	8.5	15.7	24.2	53.2	87.1	95.6	88.3	99.2
PO ₄ sol. [≡]	0.06	0.02	0.03	0.04	0.03	0.02	0.03	0.04
NO ₃ ⁻	0.33	0.37	0.41	0.21	0.37	0.28	0.64	0.28
NH ₃	0.17	0.12	0.15	0.18	0.25	0.19	0.08	0.18
Cl ⁻	2.0	2.1	2.2	3.0	4.0	4.0	6.2	4.7
SO ₄ ⁼	9.6	11.3	13.2	13.0	17.6	17.6	18.0	18.2
Total Dissolved Solids	32.0	39.0	44.7	68.7	121.8	126.0	114.7	142.0

Figure 5. Isothermal patterns ($^{\circ}\text{C}$) and Secchi-disc transparency (meters).

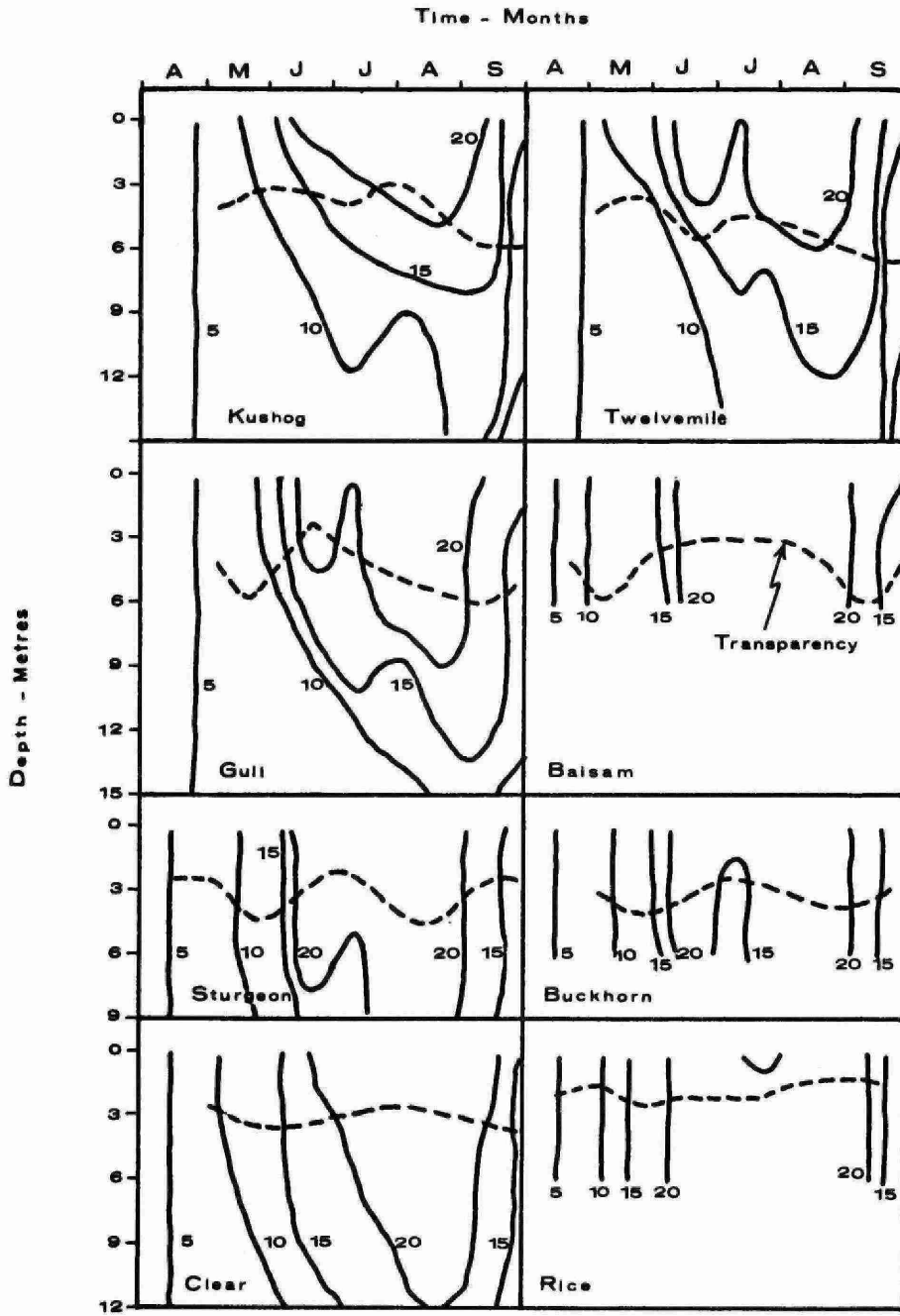


Figure 6. Comparison of lakes on the basis of total P as PO_4 (mg/l), inorganic nitrogen (mg/l), iron (mg/l), sulfate (mg/l).

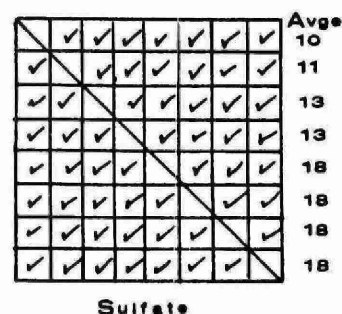
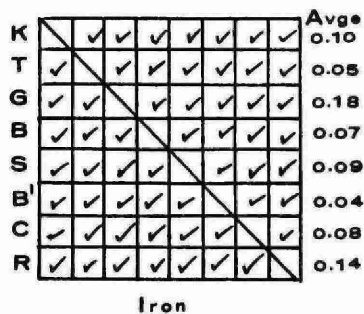
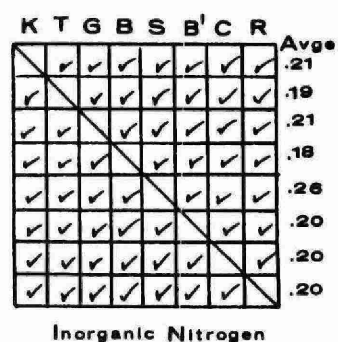
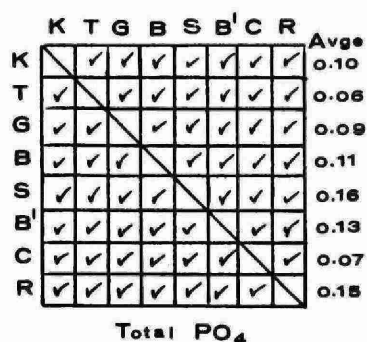


Figure 7. Comparison of lakes on the basis of Ca^{++} (mg/l), pH, alkalinity (mg/l CaCO_3), total dissolved solids (mg/l).

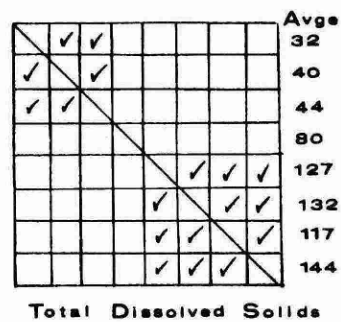
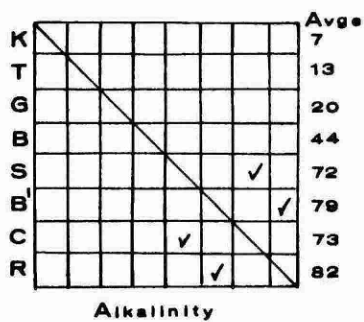
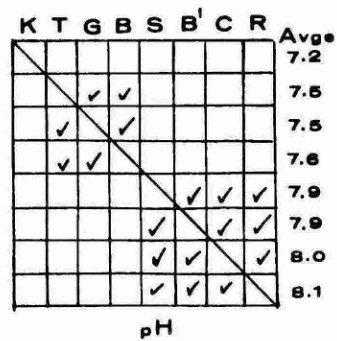
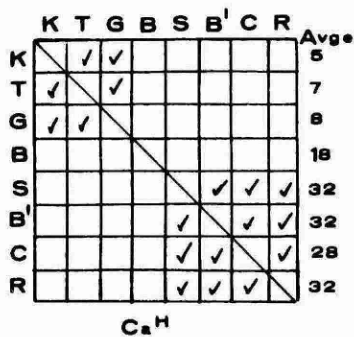


Figure 8. Comparison of lakes on the basis of transparency (metres) and average column temperatures ($^{\circ}\text{C}$).

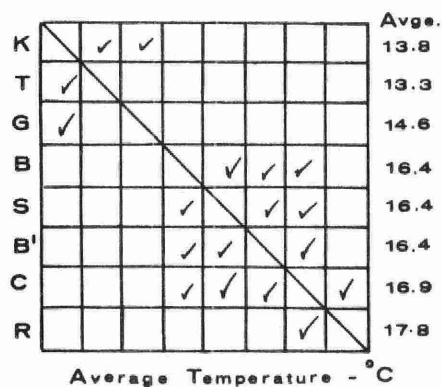
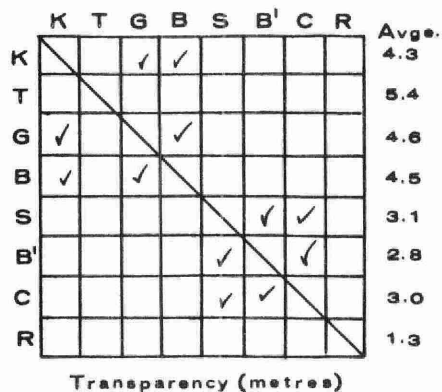


TABLE IV

Results of Various Polynomial Regression Analyses
(104 Values per Set)

Dependent Variable	Independent Variable	Regression Equation	Correlation Coefficient
ASU/ml	total PO ₄ (mg/l)	nil	nil
ASU/ml	inorg. N (mg/l)	nil	nil
ASU/ml	alkalinity (mg/l)	$Y = -247.53 + 34.59X$	0.745
Chlor. a (ug/l)	total PO ₄ (mg/l)	nil	nil
Chlor. a (ug/l)	inorg. N, (mg/l)	nil	nil
Chlor. a (ug/l)	alkalinity (mg/l)	$Y = 3.64 - 0.206X + 0.004X^2$	0.760
Chlor. a (ug/l)	ASU/ml	$Y = 1.276 + 0.0026X$	0.679
Chlor. a (ug/l)	transparency (metre)	$Y = 23.451 - 7.673X + 0.637X^2$	0.941
ASU/ml	transparency (metre)	$Y = 5833.121 - 1760.11X + 137.148X^2$	0.717
Alkalinity (mg/l)	pH	$Y = -263.748 + 40.085X$	0.580

Correlations between algae as ASU/ml and chlorophyll a concentrations, alkalinity and pH, and transparency and algal quantities are indicated.

The relationship between the maximum standing crop associated with each lake and alkalinity was also tested (Figure 9).

Alkalinity and algal production was further investigated in the laboratory using raw water from Lake Kushog (alkalinity - 12 ppm) to which quantities of oxidized or oxidizable carbon equivalent to alkalinities of 50, 25, 12.5 mg/l CaCO_3 added in the form of NaHCO_3 , glucose or in a 1/1 mixture.

Addition of carbon either as NaHCO_3 or glucose stimulated algal growth (Figure 10). Apparent inconsistencies in response to varying glucose quantities is probably related to the adaption of the microbial population to sugar availability, which with the highest sugar level, for example, could result in a decomposition of glucose to carbon dioxide at a rate faster than can be utilized by the algae. Unused carbon dioxide from this source would then pass out of the system. The decline of the algal population with time indicates, in part, a depletion of the glucose pool. Continuous feeding of glucose, rather than a single dose, would probably have resulted in a greater response with algae. The compound, NaHCO_3 , being less transitory, acted as a more persistent source of carbon which resulted in stimulations in algal growth.

Figure 9. Relationship between maximum standing crop of algae and alkalinity (mg/l CaCO_3).

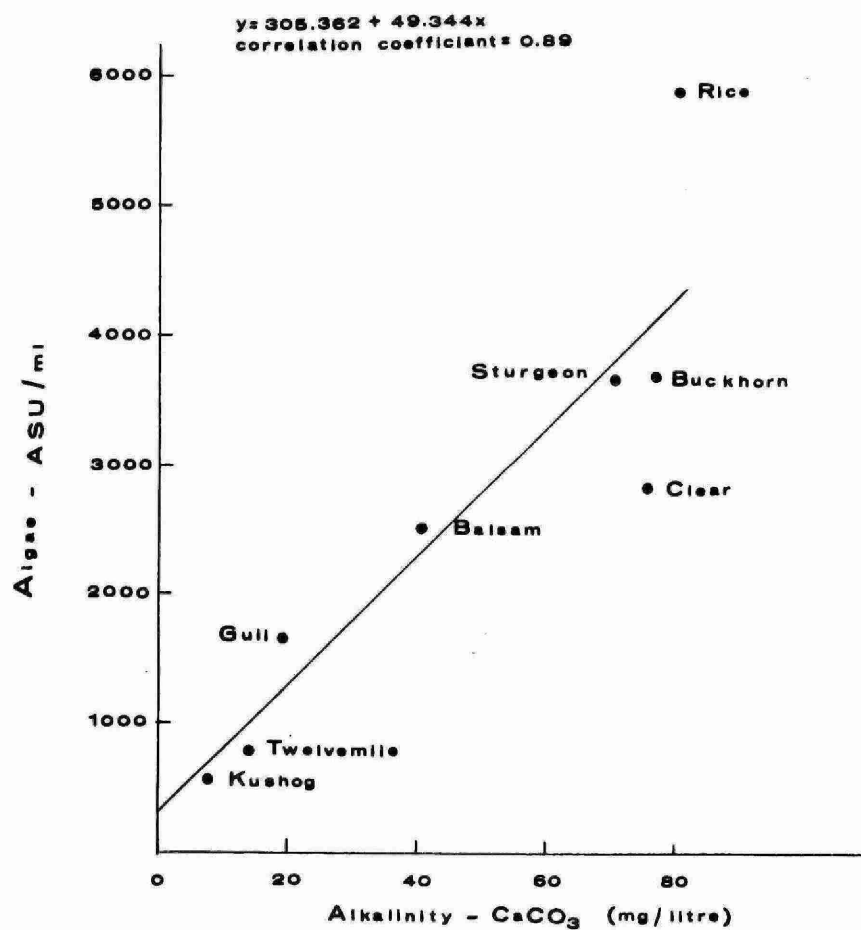
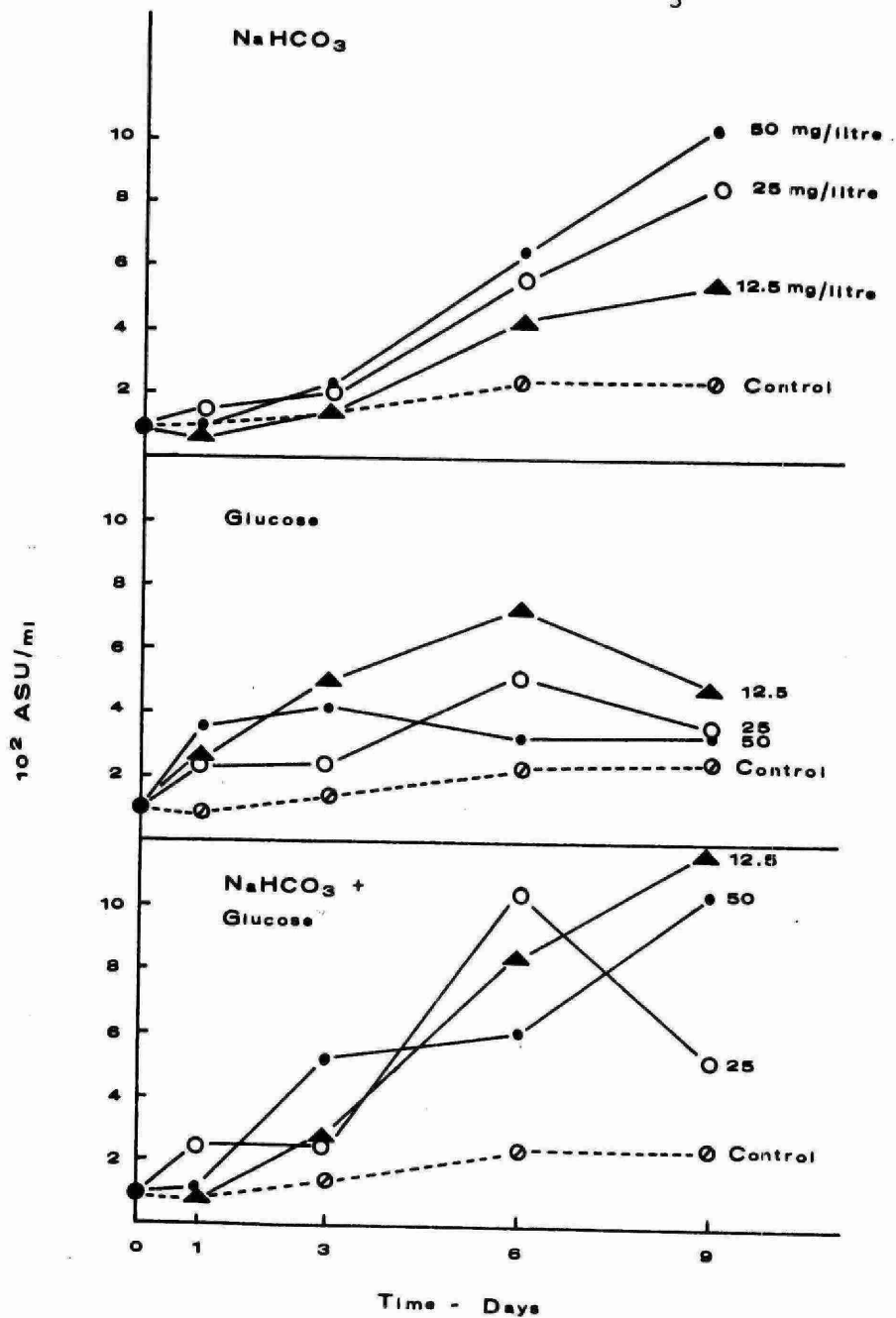


Figure 10. Effects of the addition of inorganic and organic carbon on the growth of algae (ASU/ml)
(mg/l C expressed as mg/l CaCO_3)



DISCUSSION

On the basis of total phytoplankton standing crops (ASU/ml) the eight lakes fall into two categories (Figure 3). The less productive lakes, Kushog, Twelve Mile, Gull and Balsam, are physiographically associated with the precambrian shield and limestone plain (soft water), the remaining four lakes with the till regions (hard water), illustrating a relationship in productivity similar to that noted by Rawson (1960) with lakes in Saskatchewan. Of the various algal divisions recorded the Bacillariophyta or diatoms appear to contribute most to the partition of lakes, although the Cyanophyta or blue-greens are not without effect.

Any discussion of algal production must take into consideration effects related to differences in temperature or the availability of solar energy. As less than eighty miles separate Kushog Lake from Rice Lake, with an altitude difference of less than 500 feet, all lakes could be expected to receive equivalent quantities of solar radiation. Differences between lakes with regard to light penetration or transparency (Figure 8) essentially reflect variations noted with total standing crops (Figure 3).

The rate of warming of a particular lake is, among other things, not only dependent on lake volume but also depth. It is not surprising that the three northernmost lakes, being the deepest, were found to be significantly cooler than the remaining lakes (Figure 8). If temperature was the main factor influencing algal growth, however, production in lakes having the same temperature characteristics should be

approximately equivalent, which in the case of Balsam and Buckhorn, for example, they are not (Figure 3). Water temperature also exerts a qualitative effect on the algal community (Hutchinson, 1967) but as identification in this study was restricted to genera, no discussion of these relationships can be attempted.

A comparison of the nutritional environments of these lakes suggest that hardness and alkalinity are perhaps more critical in determining the production category of these lakes rather than total phosphate, inorganic nitrogen, sulphate or iron (Figures 5, 6, 7).

Ryder (1964), in studying the chemical characteristics of several Ontario lakes relative to fish production proposed a morpho-edaphic index - total dissolved solids ppm/average depth in feet - where values in excess of 1.83 indicated eutrophy. Values obtained from the lakes of this study indicate productivity levels in approximately the same order as obtained with estimated standing crops (Figure 3) and show Kushog, Twelve Mile and Gull to be oligotrophic, Balsam-mesotrophic and the remaining lakes-eutrophic (Table V).

Physiologically, the amount and rate of algal production, as in any plant, is controlled by the availability of nitrogen and phosphorus (Hutchinson, 1967). The average requirements of these two substances in the production of the seston of each lake (assumed for simplification to be of primarily phytoplankton composition) was therefore examined (Table VI). Ratios obtained from these values are in close agreement with observations of Hutchinson (1967), Phinney and Peek (1961) and Neil et al (1967) who obtained ratios varying from 9.4 - 25.5.

TABLE V

Morpho-edaphic Index of Lake Productivity
Total dissolved solids/average depth in feet as
proposed by Ryder (1964)

Kushog	0.70
Gull	0.86
Balsam	1.76
Sturgeon	4.32
Buckhorn	6.30
Clear	2.94
Rice	7.10

Twelve Mile 0.66

TABLE VI

Average Requirements of Phosphorus and
Nitrogen in the Production of Seston of Each Lake

Lakes	Suspended Solids mg/l	Phosphorus mg	Nitrogen mg	N/P
Kushog	2.6	0.014	0.376	27
Twelve Mile	2.4	0.012	0.313	26
Gull	4.0	0.23	0.220	10
Balsam	2.6	0.024	0.284	12
Sturgeon	3.3	0.044	0.349	8
Buckhorn	4.0	0.044	0.433	10
Clear	4.0	0.013	0.377	29
Rice	7.0	0.035	0.646	18

When the N/P ratio is large, phosphorus may be limiting production (Hutchinson, 1967). One might then expect the reverse to be the case when the ratio is small, particularly as algae are known to accumulate phosphorus in excess (Gerloff and Skoog, 1957).

These ratios would suggest that in lakes having a high N/P ratio, all else being equal, an effective control in preventing excessive algal production, as has occurred in Lake Sabisticook (Mackenthun, 1968), may be achieved by restricting the input of phosphorus. In lakes having a low N/P ratio control of nitrogen input may possibly be more effective. The presence of certain blue-green algae, which are capable of fixing molecular nitrogen (Lewin, 1962), may tend to circumvent this action. Control of phosphorus input in these situations should eventually result in an environment unfavourable for the excessive development of these forms.

N/P ratios, while indicating the relative degree of availability of the two substances for algal production, obviously will not yield critical information concerning maximum permissible concentrations. In lakes that thermally stratify the optimum time to characterize the potential production of a lake with respect to nitrogen and phosphorus would be at a time of minimal biological activity and homothermal conditions (following the spring overturn), (Sawyer, 1954). Suggested levels of the nutrients which will not result in excessive algal growths are 0.01 mg/l soluble phosphorus and either 0.30 mg/l inorganic nitrogen or about

0.60 mg/1 total nitrogen (Müller, 1953; Sawyer, 1954; Sylvester, 1961). Comparing the level of the two nutrients in each lake obtained at this time (Table VII) with the above values, it is apparent that Kushog and Rice exceed the recommended level for soluble phosphorus, and Sturgeon the level for inorganic nitrogen. All lakes except Twelve Mile and Gull were in excess of the total nitrogen value.

In shallow lakes, such as Balsam, Sturgeon, Buckhorn, and Rice, recycling of nutrients into the overlying water would be expected to be dependent on the rate of benthic microbial activity which would increase with rising water temperatures during the summer. Therefore, nutrient availability based on the values in Table VII could be quite misleading and a different method for evaluating potential production in shallow lakes is necessary.

The most striking correlation obtained in this study, the linear relationship between algal quantities (ASU/ml) and alkalinity, is essentially a relationship between inorganic carbon availability and phytoplankton response. Setting a value of 2,500 ASU/ml as a maximum desirable limit for algal production, relationships between alkalinity and maximum production (Figure 9) suggest carbon availability to be limiting with respect to algal development, at alkalinities of less than 50 ppm.

Increasing the availability of carbon in a low alkalinity raw water by the addition of NaHCO_3 , glucose or both increased algal levels (Figure 9), a result which is consistent with observations of Lange (1967) who found additions of sucrose to planktonic blue-green cultures to be stimulatory only in the presence of bacteria.

TABLE VII

Concentrations of Soluble Phosphorus (mg/l)
and Nitrogen (mg/l) Following the Spring Turnover

<u>Lake</u>	<u>Soluble P</u>	<u>Inorganic N</u>	<u>Total N</u>
Kushog	0.016	0.27	0.75
Twelve Mile	0.010	0.22	0.58
Gull	0.010	0.17	0.56
Balsam	0.003	0.27	0.65
Sturgeon	0.010	0.38	0.93
Buckhorn	0.003	0.30	1.01
Clear	0.003	0.29	0.66
Rice	0.013	0.12	0.93

The results suggest that the discharge of inorganic (alkalinity) or biodegradable carbonaceous (BOD) materials to low alkalinity lakes at levels in excess of the quantities of the receiving water will increase algal production, when nitrogen and phosphorus is available in sufficient quantities.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study suggest that sufficient quantities of phosphorus and nitrogen are present in these lakes to support excessive algal production. The absence of the phenomenon in the upper lakes would appear to result from an inadequate supply of dissolved carbon (alkalinity). It is therefore recommended that the addition of oxidized inorganic (alkalinity) or biodegradable (BOD) carbonaceous materials in quantities in excess of the receiving waters be prevented with those surface waters having an alkalinity of less than 50 mg/l. As all surface waters in Ontario eventually pass into regions where carbon availability will no longer be a limiting factor with respect to algal production, control of nitrogen and phosphorus entry into all surface waters is important. Future emphasis in nutrient algal relationships should be focused primarily on shallow hard water lakes to investigate the availability of nitrogen and phosphorus via recycling within the basin. Establishment of suitable nutrient limits for this type of environment would be more than adequate for deep hard water lakes.

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